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Investigations into the Properties, Conditions, and Effects of the Ionosphere

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Northwest Research Associates (NWRA), as prime contractor, and its two team subcontractors, Science Applications International Corp. (SAIC) and the University of Lowell Center for Atmospheric Research (ULCAR), provide members of their technical staffs to conduct and support scientific and engineering investigations of the ionosphere. The investigations address ionospheric composition, structure, specification, scintillation and chemistry as well as remote sensing of the ionosphere through ultraviolet sensors. Specific work is carried out under individual Task Requirement Notices (TRNs) written for conduct and/or support of investigations in the following six categories: laboratory measurements; field measurements; aircraft measurements; rocket, balloon, shuttle, and satellite measurements; analytical and theoretical investigations; and scientific and engineering analysis. This report provides a summary of the work performed during the period 16 December 1987 through 31 December 1988.

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CONVERSION TABLE

Conversion factors for U.S. customary to metric (SI) units of measurement.

To convert from	to	Multiply by
angstrom	meters (m)	$1.000\,000 \times 10^{-10}$
atmosphere (normal)	kilo pascal (kPa)	$1.013\,25 \times 10^{+2}$
bar	kilo pascal (kPa)	$1.000\,000 \times 10^{+2}$
barn	meter^2 (m^2)	$1.000\,000 \times 10^{-28}$
British thermal unit (thermochemical)	joule (J)	$1.054\,350 \times 10^{+3}$
cal (thermochemical)/ cm^2	mega joule/m^2 (MJ/m^2)	$4.184\,000 \times 10^{-2}$
calorie (thermochemical)	joule (J)	$4.184\,000 \times 10^{+3}$
curie	giga becquerel (GBq)	$3.700\,000 \times 10^{+1}$
degree Celsius	degree kelvin (K)	$t_K = t°_C + 273.15$
degree (angle)	radian (rad)	$1.745\,329 \times 10^{-2}$
degree Fahrenheit	degree kelvin (K)	$t_K = (t°_F + 459.67)/1.8$
electron volt	joule (J)	$1.602\,19 \times 10^{-19}$
erg	joule (J)	$1.000\,000 \times 10^{-7}$
erg/second	watt(W)	$1.000\,000 \times 10^{-7}$
foot	meter (m)	$3.048\,000 \times 10^{-1}$
foot-pound-force	joule (J)	1.355 818
gallon (U.S.liquid)	meter^3 (m^3)	$3.785\,412 \times 10^{-3}$
Gauss	Tesla	$1.000\,000 \times 10^{-4}$
inch	meter (m)	$2.540\,000 \times 10^{-2}$
joule/kilogram (J/kg) (radiation dose absorbed)	gray (Gy)	1.000 000
kilotons	terajoules	4.183
kip (1000 1 bf)	newton (N)	$4.448\,222 \times 10^{+3}$
kip/inch^2 (ksi)	kilo pascal (kPa)	$6.894\,757 \times 10^{+3}$
ktap	newton-second/m^2 (N-s/m^2)	$1.000\,000 \times 10^{+2}$
micron	meter (m)	$1.000\,000 \times 10^{-6}$
mil	meter (m)	$2.540\,000 \times 10^{-5}$
mile (international)	meter (m)	$1.609\,344 \times 10^{+3}$
ounce	kilogram (kg)	$2.834\,952 \times 10^{-2}$
pound-force (1bf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N-m)	$1.129\,848 \times 10^{-1}$
pound-force/inch	newton/meter (N/m)	$1.751\,268 \times 10^{+2}$
pound-force/foot^2	kilo pascal (kPa)	$4.788\,026 \times 10^{-2}$
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (1bm avoirdupois)	kilogram (kg)	$4.535\,924 \times 10^{-1}$
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2(kg·m^2)	$4.214\,011 \times 10^{-2}$
rad (radiation dose absorbed)	gray (Gy)	$1.000\,000 \times 10^{-2}$
roentgen	coulomb/kilogram (C/kg)	$2.579\,760 \times 10^{-4}$
shake	second (s)	1.000×10^{-8}
slug	kilogram (kg)	$1,459\,390 \times 10^{+1}$
torr (mm Hg, O° C)	kilo pascal (kPa)	$1.333\,22 \times 10^{-1}$

SUPPORT OF INVESTIGATIONS INTO THE PROPERTIES, CONDITIONS, AND EFFECTS OF THE IONOSPHERE

TABLE OF CONTENTS

I. INTRODUCTION

This is an hour-rate contract under which Northwest Research Associates (NWRA), as prime contractor, and its two team subcontractors, Science Applications International Corp. (SAIC) and the University of Lowell Center for Atmospheric Research (ULCAR), are providing Members of their Technical Staffs (MTS) at negotiated hourly rates, and with reimbursement of other direct and indirect costs, to conduct and support scientific and engineering investigations into the properties, conditions, and effects of the ionosphere. Specific work is carried out under individual Task Requirement Notices (TRNs) written for conduct and/or support of investigations in the following six categories: laboratory measurements; field measurements; aircraft measurements; rocket, balloon, shuttle, and satellite measurements; analytical and theoretical investigations; and scientific and engineering analysis.

II. ADMINISTRATIVE MATTERS

Work under a given TRN is authorized only upon mailing to the contractor or sub-contractor of a corresponding contract or subcontract modification following full-cycle approval thereof (by the Contracting Officer's Technical Representative; the contractor and, if appropriate, a subcontractor; and the Contracting Officer).

III. SCIENTIFIC AND ENGINEERING PROGRESS

We report in this section the technical status of each TRN active during this report period, including the performing organization(s), start and end dates, the task Principle Investigator (P.I.), and other participating personnel. For this annual report, related tasks are grouped together. The task activity report combines a condensed summary of work completed during the first three quarters with a more detailed discussion of activities performed during the last quarter. Please refer to the quarterly reports for a more detailed discussion of previous activities. A report is included on all TRNs active during the reporting period.

A. METEOR SCATTER (TRN 16 and 19)

Performing organization: ULCAR,
Dates: 16 through 31 December 1987
Personnel: J. A. Weitzen and E. Li

The objectives of the work performed under this TRN were to develop and provide continuing support for meteor scatter analysis software and to support the implementation of control and interface systems for data acquisition and on-site analysis. Specifically, we provided AFGL/LID with the capability to process data from the High-Latitude Meteor-Scatter Test Bed. Software that initially was developed by RADC/EEPS (RADC-TR-86-165; ADA174672) was modified to be operable on either a mainframe VAX or an IBM-

PC/AT-compatible computer. A package of analysis routines was developed to ascertain the effects of a polar-cap absorption event.

The meteor-trail classification software (AUTOCLASS 1.5, cf. RADC-TR-86-117; ADA173133) was modified to run without operator intervention. The fully automated classification program (AUTOCLASS 2.0) was documented and evaluated by comparing the results with those obtained manually by an experienced meteor-scatter scientist. This comparison (1000 data records) revealed a significant improvement, as there were no first-degree errors (sporadic E classified as a meteor trail) and less than two percent second-degree errors (meteor trail classified as sporadic E). Disagreements between the auto-classification and the expert occurred on less than five percent of the records. This compares favorably with the approximate ten percent error rate for AUTOCLASS (without operator intervention) and five to eight percent with operator intervention.

With the upgrade to a continuously recording, dual-polarization, six-frequency system, the analysis software should be modified further . These new data would provide an improved capability to distinguish overdense trails from sporadic E. Plans were drafted to modify the software. A PC-controlled receiver data-acquisition system was developed and deployed to Thule AB, Greenland, and reported by Li (1988), as an interim technical report.

B. BERMUDA IONOSONDE TESTS (TRNs 20 and 24)

Performing organization: ULCAR
Dates: 16 December 1987 through 30 September 1988
Personnel: D.F. Kitrosser and K. Bibl

The objectives of the Bermuda ionosonde work completed under TRNs 20 and 24 were to locate a Digisonde 256 at Hamilton Naval Air Station, Bermuda and to operate the ionosonde using the lowest possible power level, consistent with good data. The Government "goal is to permanently locate a Digisonde 256 at that [Bermuda] location requiring low RFI to other users of the HF band."

Initial concern was directed toward siting and operating modes to reduce radio frequency interference to acceptable levels for an installation at the opposite end of Bermuda. approximately 20 miles away. This concern was alleviated and a routine half-hourly, low power (150 watts) peak pulse power schedule was established. A remote terminal was also provided to the installation that enables personnel to turn the Digisonde off if RFI becomes objectionable.

A nearby Anti-submarine Warfare Operations Center (ASWOC) that uses an HF communications network experienced bothersome RFI. The close proximity (within 200 yards of the Digisonde transmit antenna) requires signal isolation (blanking) that was achieved with a University designed and built "antenna clipper." The clipper disables the

ASWOC receive system during the Digisonde transmit pulse. The clipper was successfully installed and tested. Navy acceptance tests indicated the interference was reduced to tolerable levels but the VSWRs are not within acceptable levels. Another remote terminal was provided to the ASWOC to provide means for disabling the Digisonde in the event of objectionable RFI. The Digisonde 256 continues to operate on a temporary, routine basis in anticipation of Navy approval for permanent operation. Given Navy approval, two tasks are no longer appropriate i.e., return of the Digisonde and trailer to the University of Lowell and refurbishment of the Digisonde as needed to meet the original specifications. A summary report was prepared (Kitrosser *et al*, 1988).

C. OVER-THE-HORIZON RADAR TEST SUPPORT (TRNs 21 and 24)

Performing organization: ULCAR
Dates: 20 December 1987 through 30 November 1988
Personnel: G.S. Sales, B.W. Reinisch, and J.G. Moore

The objectives of the OTH Radar support completed under TRNs 21 and 24 were to provide a flight qualified Mission Director and scientist/engineer personnel for radar and AFGL research flights, to evaluate OTH environmental assessment performance, and to repair (including emergency response for Argentia and Goose Bay) and upgrade Digisondes at Argentia, Newfoundland; Goose Bay, Labrador; and Qanaq, Greenland.

Mission Director and scientist support were provided for Airborne Ionospheric Observatory (AIO) flights conducted from Norway January 4-21, 1988. Scientist support was provided for selection of the optimum Digisonde 128PS operating modes onboard the AIO. A coordinated series of measurements was made to investigate several aspects of the auroral zone:

a. Variation with altitude of the spectrum of ionospheric irregularities in the post-sunset local time sector.

b. Relative motion between drifting auroral arcs and the background ionospheric plasma in the evening sector.

c. Behavior of dayside auroral arcs especially when they move poleward of Spitsbergen, Norway.

The experiments involved coordinated measurements with the Defense Meteorological Satellite Program (dawn-dusk satellite, F8), the European Incoherent Scatter Radar, and the University of Oslo optical instrumentation in Spitsbergen. The aircraft missions (cf. Reinisch *et al.*, 1988) were staged out of Andoya, Norway; inclement weather required one aircraft recovery at Bodo, Norway.

Mission Director support was provided for AIO research missions conducted on the ground at Thule Air Base, Greenland February 2-22, 1988 (cf. Reinisch *et al.*, 1988) and

November 29 to December 16, 1988 (cf. Appendix A for the expedition profile). These missions were conducted as part of Project CEDAR, an international cooperative study program to determine the coupling energetics and dynamics of atmospheric regions. The Air Force Geophysics Laboratory work centers on the determination of large scale auroral motions, ionospheric dynamics, and radio scintillation effects in the central polar cap. Observations of ionospheric densities and motions were made with the AIO Digisonde 128PS from the ground at Thule. These observations were conducted during darkness throughout the aforementioned periods. Results of these campaigns, as logistically supported by this contract, are being combined with the scientific results obtained from other contracts and organizations and reported elsewhere (e.g. Reinisch *et al.*, 1989).

Airborne Ionospheric Observatory flights were conducted in December 1987 (cf. Reinisch *et al*, 1988) to serve as a dedicated target for checkout and test of the OTH-B radar emulator. Aircraft Digisonde 128PS and Barry chirp sounder data were gathered during the flights. These data provided information to evaluate the performance of the OTH environmental assessment. The sensitivity of the maximum usable frequency (MUF) variations to ionospheric changes in the reflection region reveal the criticality of providing the radar operators tools to use such information when it is available. These experiments showed that coordinated data gathering by the radar and supporting ionosonde sites is required to fully evaluate the radar frequency management procedures. It was also shown that the radar backscatter sounder's upper frequency limit of 28 MHz limited the utility of the data for daytime radar frequency management for these experiments. A letter report was prepared that summarized the flight routes, objectives and preliminary technical results obtained from these experiments and analyses.

Repairs and upgrades were made to the Argentia, Goose Bay and Qanaq Digisondes. Fall 1988 visits were conducted to each of the instruments (two visits each to Goose Bay and Argentia; one visit to Qanaq). A trip was also made to Wright-Patterson AFB, Ohio to assist in preparing the AIO for the Fall 1988 CEDAR Campaign. A new antenna switch, uninterruptible power supply, Multitech modem, surge suppressor, and 14 new final power amplifier tubes were installed and tested at Argentia. At Goose Bay, an antenna switch was installed containing a rubidium oscillator and provisions for two additional antennas needed for oblique sounding. The final power amplifier was modified to improve the pulse shape by eliminating a transient spike appearing in the RF pulse output. The latest remote terminal software was installed at Goose Bay. A December 1988 visit was made to Qanaq for routine maintenance of the Digisonde to ensure proper operation for the CEDAR campaign.

D. ADVANCED SPACE FORECASTING COURSE (TRN 22)

Performing organization: ULCAR
Dates: 28 April through 15 July 1988
Personnel: A.L. Synder

The objectives of this task were to prepare and teach a four week course entitled "Advanced Topics in Space Environmental Forecasting." The course was prepared and subsequently presented at the Air Force Global Weather Central May 2, through May 27, 1988. The course was presented in six hour blocks, five days per week with time split about equally between lecture/discussion and laboratory exercises. The exercises were centered around understanding the uses and limitations of the data sets and models available to the Global Weather Central. A summary report was prepared (Snyder, 1988).

E. OBLIQUE-PROPAGATION EXPERIMENT AND AUTOMATIC TRACE IDENTIFICATION AND SCALING DEVELOPMENT (TRN 21)

Performing organization: ULCAR
Dates: 29 July through 30 November 1988
Personnel: W.S. Kuklinski and B.W. Reinisch

The objectives of this work are divided into two categories -- experimentation and algorithm development. Instrumentation and equipment is to be prepared, installed and tested that enables oblique propagation experiments; and algorithms are to be developed for automatic oblique ionogram trace identification and scaling. The project has been titled Digital Oblique Remote Ionospheric Sensing (DORIS). The goal is to determine midpath ionospheric information in the form of an equivalent electron density profile and a derived vertical incidence ionogram (virtual height trace) determined from an oblique ionogram for the midpoint region of the oblique link.

The Goose Bay Digisonde was modified for oblique propagation experiments by adding transmit and receive antenna switches, rubidium time standard and control software. A rotatable horizontal log periodic transmit/receive antenna was purchased, installed, and tested in conjunction with the Wallops Island, Virginia Digisonde. Initial propagation experiments were conducted over the Goose Bay to Wallops Island path. The results of the initial experimentation are being used to test the DORIS trace identification algorithms.

The oblique ionogram scaling algorithm is represented as a number of separate, interrelated functional operations including: noise/interference suppression; trace enhancement; trace identification; conversion between scaled oblique echo traces and the equivalent vertical midpoint traces; and echo height inversion. The specific details of the final functional oblique ionogram scaling algorithm will depend on a number of system factors (e.g., oblique path geography, availability of polarization data, transmit power and waveforms). However, application of adaptive signal processing and pattern recognition

techniques will provide flexibility to incorporate the algorithm with the Digisonde 256 hardware and software.

During this reporting period, the noise/interference suppression and trace enhancement components of the endpoint-vertical-ionogram-based oblique scaling algorithm have been implemented and tested using a limited set of oblique ionograms. Data collected over the Goose Bay to Millstone Hill, Massachusetts and the Goose Bay to Wallops Island paths are being used to further test these algorithms and to develop the oblique trace identification algorithm. An Interim Technical Report was prepared (Kuklinski *et al*, 1988). A second report (Kuklinski *et al*, 1989) is in preparation that summarizes progress toward the trace identification algorithm.

F. ARTIST STATUS AND IMPROVEMENTS (TRN 21)

Performing organization: ULCAR
Dates: 29 July through 30 November 1988
Personnel: J. Tang and B.W. Reinisch

The purpose of this work was tc report on the current status of the Automatic Real Time Ionogram Scaler and True Height (ARTIST) software and make improvements to it.

The baseline ARTIST was completed in October 1986, documented and delivered to the Sacramento Air Logistics Center to fulfill the requirements of contract F04606-85-C-0810. With the more than two years field experience with the 1986 ARTIST, it was realized that additional developments would improve the resulting ionospheric data and the system reliability. The development work is in three categories:

- Improve scaling and true height profile analysis.
- Automate the measuring of ionospheric plasma drift data and the recording of these data on magnetic tape.
- Improve input/output operations and the diagnostic programs for testing communication ports.

An Interim Technical Report was prepared to document the ARTIST developments beyond the aforementioned baseline (Tang *et al.*, 1988[a]).

Work to improve ARTIST has proceeded in three areas:

- Improve the identification of multiple sporadic E traces.
- Improve configuration management through the use of version numbers for each subroutine, module, and the entire ARTIST algorithm.

- smooth the virtual height h'(f) trace.

A multiple sporadic E trace identification algorithm has been developed and implemented in the latest version of ARTIST. The version number implementation is complete. The use of Robust Regression (RR) methods is being explored as a technique to smooth the h'(f) traces. An Interim Technical Report was prepared to summarize progress toward the ARTIST improvements (Tang *et al.*, 1988[b]).

G. STUDIES OF HIGH-LATITUDE AND EQUATORIAL SCINTILLATION AND TEC USING GPS (TRNs 14, 23, and 29)

Performing Organization: NWRA
Dates: 16 December 1987 through 31 December 1988
Personnel: C.C. Andreasen, M.J. Klein, J.M. Lansinger (P.I.), and R.M. Bussey

1. Objective.

The unified objective of TRNs 14, 23, and 28 was to advance understanding of scintillation and TEC effects on transionospheric RF systems under disturbed conditions. Most of the work addressed these effects at polar latitudes (TRNs 14 and 29) during the early rising phase of the solar activity cycle, at both high and low elevation angles. Comparative measurements also were made through the sub-auroral (TRNs 14 and 29) and equatorial (TRN 23) ionosphere during elevated (but not maximum) solar activity.

The work required maintaining reliable operation of Global Positioning System (GPS) receivers located at AFGL and Thule AFB, Greenland, and fielding such a receiver during an excursion to Kwajalein, Marshall Islands. It also involved acquisition and analysis of high-quality data to advance empirical characterization of ionospheric scintillation and TEC affecting transionospheric RF systems.

2. High-latitude Operation and Maintenance of GPS Receivers and Ancillary Equipment.

Reliable operation of the GPS receivers at AFGL and Thule was crucial to successfully meeting scientific objectives. Under these TRNs, we provided engineering and technical support to enhance the operation of both receiver systems. The GPS receivers at Thule are operated by a Danish contractor. Under our responsibility to ensure reliable operations at Thule, we communicated with that contractor's technicians by telephone and made onsite visits to diagnose and fix problems and to implement new or revised testing and operating procedures.

Early in the year, Mr. Andreasen traveled to Thule to perform routine calibration of the primary GPS system. During calibration, he found that the test transmitter did not meet specifications. He made the necessary repairs at AFGL and returned the functioning test transmitter to Thule on a later trip.

A secondary GPS receiver was set up at Thule and configured to acquire data at low elevation angles. Data acquisition was not successful initially due to malfunction of the antenna, but parts obtained from AFGL rendered the secondary system operational. Subsequent tests revealed additional malfunctions, however, which necessitated turning the systems off and returning to AFGL for repairs. On a later trip, the primary GPS system was installed and programmed to receive signals from satellites at high elevation angles, and the secondary system was configured to receive from satellites at low elevation angles concurrently.

Additional tasks, at AFGL, involved repair of disk and tape drives. Mr. Andreasen developed a procedure to copy files between tape drives on the PDP-11-03 computer. A procedure was developed also to provide quick reference and a catalog of active events acquired with Raytheon's phased-array radar.

3. Equatorial Operation and Analysis.

During August, we deployed the GPS receiver normally operated at AFGL to Kwajalein Atoll, Marshall Islands, in conjunction with a multi-instrument joint campaign between AFGL and the Defense Nuclear Agency (DNA). (See also TRNs 25 and 28.) Mr. Andreasen met Mr. Lansinger at Kwajalein and set up the GPS receiver on Roi-Namur Island on 30 July, near the DNA/NWRA transportable satellite receiver, "Rover." (Rover collected data from the HiLat and Polar BEAR satellites.) Following checkout and initial operation of Rover, Mr. Lansinger returned to the west coast. Mr. Andreasen operated Rover and the GPS receiver thereafter, returning to the east coast on 4 September.

Scintillation and TEC data were acquired by means of GPS during 19 days between 3 and 25 August, 295 hours of such data being collected. Data were lost during the other four days of the interval, primarily due to tape-drive problems. Scintillation activity levels were fairly high during the collection period, and valuable data were collected and saved on computer tape and strip charts. The data were returned to AFGL for analysis, which has been complicated by loss of one of the two differential carrier-phase records. The missing record normally is used to provide continuity near 2π crossings of the primary record. Its absence requires additional data handling and preparation. Details and analysis results will be provided in the final report on TRN 23.

4. Improvements to the Data-collection System.

To facilitate operation at Thule by Danish technicians, Mr. Andreasen developed a dual-language option to provide Danish or English prompts, selectable by the operator, and installed it in all GPS software. Thorough testing of this modification was performed prior to site installation.

The GPS data-collection system was revised to provide additional features and refinements that enhanced performance. Programming services involved work on satellite

'window' entry, display, and update routines. To assist in day-to-day operations, a utility routine was written that performs a tape-to-tape copy of GPS files written in non-standard blocks on streamer tape drives. An additional routine was written that allows for the assessment of system performance by providing a printout of selected data for a quality-control review.

Further revisions were made to the satellite 'window' entry, display, and update routines to allow automatic updating of window entries according to date. Data-collection routines were improved to enhance reliability and speed. To facilitate processing of GPS data at a later time, a header record that stores pertinent information was added to each pass. Information stored on the header includes satellite number, data-collection date, and operator name. Utility programs were revised to accommodate this new header record.

5. BMEWS Radar Study.

Improvements were made last year to the GPS data-analysis software to allow identification and analysis of significant ionospheric events. The upgrade allowed the real-time data-acquisition software this year to produce absolute TEC data that are free from multipath contamination. It also facilitated compilation of useful scientific data both from the measurements made this year at AFGL and Thule and from many months of previously existing GPS data. Analysis of Thule data included cataloging it and locating and categorizing specific events of interest. These data have shown simultaneous large TEC variations, L-band phase and amplitude scintillation, and UHF amplitude scintillation.

In coordination with AFGL personnel, Mr. Klein provided programming services that permit identification of significant ionospheric events in terms of their magnitude, duration, and occurrence frequency. The technique utilizes relative TEC measurements derived from GPS data, and the results are presented in tabular and graphical formats, including a plot of the probability curve. The revised system was employed to process new data and to reprocess some older data.

6. Summary.

Work on these TRNs was completed during this report period, and final reports are in preparation. Features in the TEC data collected at Thule, Greenland, during the period from August 1987 through March 1988 were correlated with scintillation effects observed at 250 MHz, and the resulting correlation database was analyzed to produce a probability-of-occurrence curve for the scintillation effects observed. Details of this analysis and the results can be found in the final report on TRN 14. Subsequent data collection and analysis will be described in the final report on TRN 29.

H. IONOSPHERIC EFFECTS ON SPACE-BASED RADARS (TRN 15)

Performing Organization: NWRA
Dates: 16 December 1987 through 28 February 1988
Personnel: E.J. Fremouw (P.I.) and J.A. Secan

1. Objectives.

The Air Force and the Navy considered development of space-based radars (SBR) for purposes of defense surveillance. System configurations considered included sufficiently low frequencies and grazing angles and sufficiently large apertures (synthetic or otherwise) that the effects of the ionosphere on the radar propagation path had to be included in the considerations. The objectives of this TRN were to advance understanding of ionospheric effects on space-based radars, to identify areas of shortfall in analysis or data to meet design needs, and to develop approaches to mitigate shortfalls.

2. Workshop.

Toward the foregoing ends, AFGL organized a workshop to bring together engineering organizations responsible for system design and research organizations active in identifying and characterizing ionospheric effects. Among the potentially adverse effects considered were those arising from refractive and diffractive forward scattering through narrow angles by plasma-density irregularities, collectively termed "radiowave scintillation." Under this TRN, we conducted an assessment of the suitability and limitations of available computer models of scintillation, for presentation and discussion at the workshop. Our assessment was summarized in an Interim Technical Report (NWRA-CR-87-0014) on this TRN. We also assisted AFGL in logistical preparations for and followup on the workshop and participated therein. Mr. Secan presented our scintillation-model assessment in a talk at the workshop.

3. Conclusions.

During January and February of 1988, we reviewed and evaluated the workshop results, concentrating on specific shortfalls in models and in analysis of existing data and on needs for specific new data sets. We summarized this review in the Final Technical Report on this TRN, dated 28 February 1988. The three major conclusions from the review are as follows:

- Faraday rotation must be considered at L Band, and linear polarization should be avoided at lower frequencies.
- The strength, spatial spectrum (which dictates the backscatter frequency dependence), and degree of magnetic-field alignment of plasma-density fine structure in the F layer, which may be capable of producing radar clutter,

should be ascertained, as should the doppler spectrum of the backscatter that it would produce.

- Scintillation is the most likely threat to SBR performance, especially at low frequencies and/or low grazing angles on the ionosphere (or on elongation axes of the scattering structures).

Foremost among the shortfalls in the most widely used scintillation model, WBMOD, were the following:

- The complex signal's space-and-frequency and time-and-frequency mutual coherence functions were not calculated.

- The seasonal/longitudinal dependence of scintillation at high latitudes is not included.

- Only a single regime was employed in the power-law spatial spectrum describing scintillation-producing irregularities.

A two-regime spectrum now has been incorporated into WBMOD, as a result of the Workshop. The seasonal/longitudinal deficiency will be remedied in on-going work. We recommended that the width of the time-and-frequency mutual coherence function (i.e., the signal ambiguity function) in time (and/or space) and frequency (and/or angle) be added to WBMOD. The temporal and spatial widths, τ_0 and l_0 respectively, have now been added.

In addition, we noted one relevant shortcoming in propagation theories commonly employed to characterize and/or mitigate ionospheric effects. Ionospheric structures are almost always dealt with in one or the other of two scale-size limits. The structures are assumed to be either (a) large enough that individually they extend completely through any region of irregular plasma density along the line of sight, in which case propagation through them is treated deterministically or (b) small enough that any scattering layer is many irregularities thick along the line of sight, in which case statistical propagation theory is used. The former regime is usually thought of as the TEC (total electron content) regime and the latter as the scintillation regime.

Structures intermediate in size (tens of km) between the foregoing two limiting regimes are relevant to SBR performance (e.g., in the focusing and defocusing of synthetic-aperture antenna beams). The shortcoming is that propagation theories commonly used for synoptic purposes (as opposed to fundamental application of Maxwell's equations and/or the resulting wave equation to fully and specifically described media) do not treat them properly.

One practical result of the theory deficiency is that the variance of phase is taken to be proportional either to the incidence angle on the ionosphere (scintillation result) or to the square of that angle (TEC result). This difference can amount to almost an order-of-

magnitude difference between the ratio of phase variance near the zenith and that at low elevation angles. Present synoptic theory does not treat the transition between these two results at intermediate scales.

Regarding data shortfalls, we pointed out that the greatest need is for an accurate assessment of the solar-cycle dependence of scintillation at equatorial, auroral, and, especially, polar-cap latitudes. We noted that observing programs are under way at high latitudes but that the deficiency is not being addressed at equatorial latitudes.

Finally, we point out another shortcoming in (use of) scintillation models. Existing models fundamentally are climatological in nature, more suited to design studies and systems planning than to real-time use. Ionospheric and geomagnetic data bases amenable to updating by means of real-time observations using operational satellites and ground-based facilities, however, do exist (e.g., at Global Weather Central of the Air Weather Service). Proper links between such data bases and models such as WBMOD could render the combination suitable for real-time channel assessment and mitigation. One use of such a capability might be to determine appropriate times for employing methods described at the Workshop for reducing propagation-induced phase errors in coherent systems. These mitigation methods could be employed either in real time or, in some applications, retrospectively.

I. STUDIES AND TECHNICAL SUPPORT (TRN 25)

Performing organizations: NWRA, SAIC, ULCAR
Dates: 16 December 1987 through 30 September 1988
Personnel: E. J. Fremouw (P.I.)(NWRA), B. W. Reinisch (ULCAR), and E. Szuszczewicz (SAIC)

The objective of TRN 25 is to perform studies for and provide support to the Ionospheric Physics Division on technical tasks to include ionospheric propagation, experimental program planning, and high-latitude auroral effects. Integration of task reports to produce overall project quarterly and annual reports also is carried out under this TRN.

Two trips by Dr. Fremouw to AFGL pertained to -- and were partially funded by -- this TRN. One, in February, was for the purpose of planning the joint AFGL/DNA 1988 Propagation Effects Assessment at Kwajalein (PEAK 88) field campaign. (See also TRNs 23 and 28.) The other was to explore (a) the utility of developing an optical-disk capability for rapid access to AFGL/LIU's large data base from the Auroral and Ionospheric Remote Sensor (AIRS) on the Polar BEAR satellite and (b) possible application of the AIRS data base to a search for the "atmospheric holes" that have been postulated in the literature to arise from a flood of "mini-comets" impinging upon the earth.

Dr. Szuszczewicz also travelled to AFGL under this TRN, for technical discussions regarding AFGL participation in NASA's Aero-assisted Flight Experiment. Following up

on those discussions, he engaged in planning the configuration and flight of an AFGL mass spectrometer in conjunction with that experiment.

Periodic management and technical planning meetings were held between ULCAR and AFGL/LIS personnel. These meetings were useful in defining priorities for ULCAR support to meet short-term objectives and for defining work to best support achievement of long-term objectives. During these meetings, action plans for Project DORIS (Digital Oblique Remote Ionospheric Sensing) were developed, ULCAR support for the OTH-B Radar Program was specified, and the ground-station maintenance/upgrade requirements were defined.

J. AURORAL IONOSPHERIC REMOTE SENSOR (AIRS)

1. Image-processing Software Development and Data-management Support (TRN 26).

Performing organization: NWRA
Dates: 16 December 1987 through 15 December 1988
Personnel: R.M. Bussey, D.F. Collins, E.J. Fremouw, F.J. LeBlanc, J.M. Lansinger, R.D. Lucas (P.I.), I. Oznovich, L.A. Reinleitner, N.W. Rosenberg, J.A. Secan

a. Development of AIRSGEO and OMNI

Work at NWRA in Bellevue on this TRN focused on the development of tools for the geometric restoration of AIRS images and for general image and graphics processing. The latter tools are intended to support the joint analysis of combined image data from AIRS and ASIP (all-sky imaging photometer) and relevant non-image ionospheric data. These tools have evolved from software originally developed in another AFGL-sponsored project (contract number F19628-84-C-0131) aimed at providing a hardware/software workstation for the analysis of ASIP image data.

AIRSGEO is the name of the geometric restoration code developed to project AIRS images onto arbitrary map coordinates. (See Lucas and Robins, "Geometric Restoration of Satellite Data," NWRA-CR-87-R019.) The program OMNI provides comprehensive tools for the manipulation of image data and the construction of graphics products. Although OMNI has, for the most part, been developed within our ASIP workstation project, it is intended to be a general tool not limited to ASIP data.

OMNI runs on an AT-compatible computer with the ITI Series-100 image processing board. It is designed to be a "friendly" (i.e., easy to use) toolkit providing general image processing and graphics functions, including the following:

- image load and save
- look-up table definition, load, and save

- general image processing (convolution filters, pixel transformation, area/row/column move and copy, subimage rotate, etc.)
- ITI Series-100 register read and assign operations
- interactive cursor controls, including zoom/pan/scroll
- statistics including histograms of arbitrary subimage areas
- graphics operations including data scaling, linear and logarithmic axes, symbols, dashed, dotted, and solid lines, etc.
- text annotations
- command macros
- user-defined variables (define, assign, increment)
- begin/end loops.

The user controls OMNI with either typed commands or menu selections. In the menu mode, extensive help text describing the usage of all functions and their parameters is presented automatically. At any time, the user can switch back and forth between the menu and command modes. The latter is more efficient when the user is familiar with the desired functions. There are approximately 250 functions available, including almost all of those in the ITEX100 image-processing library plus an extensive list of functions for graphics and text annotations.

OMNI can be used to manipulate arbitrary image data and construct complex overlays of image data from multiple sources (multiple wavelengths, AIRS plus ASIP images, etc.), geographic image data (coastlines, latitude, and longitude lines), X-Y plots of correlative data, and annotations. Lists of OMNI commands can be created with a text editor and then played back using the OMNI macro facility. Operations requiring iteration can be defined with the begin/end loop construct and variable manipulations.

The OMNI functions specific to AIRS data are three optional look-up table (LUT) defining commands that generate specific ITI input and output LUTs that transform raw AIRS image data (counts) to intensity in units proportional to Rayleighs. The OMNI code was installed on one of the PC/AT-FG100 systems at AFGL/LIU on 11 May during a visit to the Laboratory by Dr. Lucas. Its architecture is very flexible, so that new functions, written in C, can be added easily. The "help" information is maintained in an external database that also can be updated easily.

AIRS images show ultraviolet backgrounds at selected wavelengths, with activity in the auroral oval and polar cap superposed. They indicate regions where communications

and radar may be adversely affected, and features such as sun-aligned arcs can be seen. Several processing and display techniques have been developed to enhance interpretation of the data. AIRS resides on the Polar BEAR satellite, which also carries a radio beacon for propagation measurements. Tracks of the penetration points of the beacon propagation path with the ionospheric E and F layers can be plotted on the images to study relationships between optical emissions and scintillations. The "mulband" program can be used to combine two simultaneous images at different wavelengths to show regions where one emission predominates over the other -- e.g., nitrogen 1544Å and oxygen 1304Å emissions.

b. Other Developments and Data Management

Other analysis aids were installed on LIU computers during an extended visit to AFGL by Mr. Oznovich in October. Important for analysis of day-side AIRS UV data is introduction of a Chapman-function correction for the contribution to image intensity by solar flux. Useful for assessment of the magnetospheric disturbance state when an image was obtained, as well as for studies of auroral morphology, is a means for comparing auroral arcs with nominal auroral-oval location. During a one-day visit by Dr. Collins, procedures were planned for analyzing star images from UV Imager II for the purpose of determining atmospheric transmission for rocket-plume photometry. Mr. LeBlanc provided part-time support in data management to AFGL/LIU at the laboratory throughout the year.

2. Data Management and Mission-planning Support (TRN 28).

Performing organization: NWRA
Dates: 27 July through 30 September 1988
Personnel: C.C. Andreasen and J.M. Lansinger (P.I.)

a. Objective and tasks

The objective of this TRN was to aid AFGL/LIU in deriving useful products from the AIRS satellite imager experimental data on a timely basis. The tasks to be performed included (1) demonstration of rapid recovery of AIRS data following both nighttime and daytime overpasses of the Polar BEAR satellite in the vicinity of Kwajalein, Marshall Islands, and (2) a study of ways to conduct coordinated ionospheric experiments making maximum use of data from UV imagers such as AIRS, using the joint DNA/AFGL 1988 Propagation Effects Assessment at Kwajalein (PEAK 88) as an example. (See also TRN 23.)

b. Operations on Roi-Namur Island

The DNA/NWRA transportable satellite receiver, "Rover," was deployed to Kwajalein and set up to receive data from the HiLat and Polar BEAR satellites on Roi-Namur Island, as part of PEAK 88. Operation of the receiver began on 30 July and ran through 29 August. Upon verification of adequate performance of the Rover receiver,

K. INVESTIGATION OF STRATOSPHERIC/MESOSPHERIC ELECTRON SAMPLING PROCESS (TRNs 17 and 30)

Performing organization: SAIC
Dates: 22 December 1987 through 30 September 1989
Personnel: E. Szuszczewicz, G. Earle, C.-L. Chang, and D. Rault

1. Overview

SAIC presented the results from a two-phase study that supported the AFGL/LID activities to measure "in situ" the free-electron population in the 40-85 km altitude regime. Exploring a species-conversion technique and parachute-borne mass spectrometer sampling, the first phase of the study focused on the design of the detection scheme and the development of appropriate models from which to extract ambient charged-particle densities from the "in situ" measurements. The second phase focused on an analysis of the data, its interpretation relative to instrument performance and ambient particle densities, and the comparison of the observation will model predictions. SAIC presented the results of both phases. A third phase (laboratory simulations), with its results, are presented in a separate and substantially more detailed year-end report.

2. Brief Statement of the Problem

A rocket-borne mass spectrometer was launched by AFGL/LID at Wallops Island, VA to an 86 km apogee. Parachute deployment and ion sampling were initiated on the upleg trajectory, with mission emphasis on ion sampling in the altitude range 75-45 km on downleg. The launch, deployment and sampling scenario are illustrated in the top panel of Figure 1.1. The sensor was a quadrupole ion mass spectrometer capable of positive and negative ion sampling modes. Its aperture plate was flush mounted with the forward surface of the main payload body (see lower panel of Figure 1.1). Forward of the aperture plate was a charged-particle flow control cell (called a 1-D ion flux cell) designed to confine charged-particle motion to one dimension by the application of bias potentials to a parallel-plate geometry. The ion flux cell, shown in more detail in Figure 1.2, had a forward injector "plate" constructed from an open helix with 0.08" holes for forward injection of SF_6.

While the measurements involved ion composition, the ultimate objective was the determination of the ambient free electron population, through conversion to negative ions (SF_6^-) by SF_6 injection at the forward plate (injector plate) of the 1-D cell. The cell design is illustrated in Figure 1.2.

The approach to N_e measurement is based on the conjecture that the ambient free electron population will be directly related to the induced negative ion population (i.e. SF_6^-) because of its rapid attachment to SF_6. Collisionality, heavy particle fractionation, neutral SF_6 distribution, negative ion attachment time, flowfield effects, and electric field collection efficiencies all contribute to the exact relationship between the free electron density and the

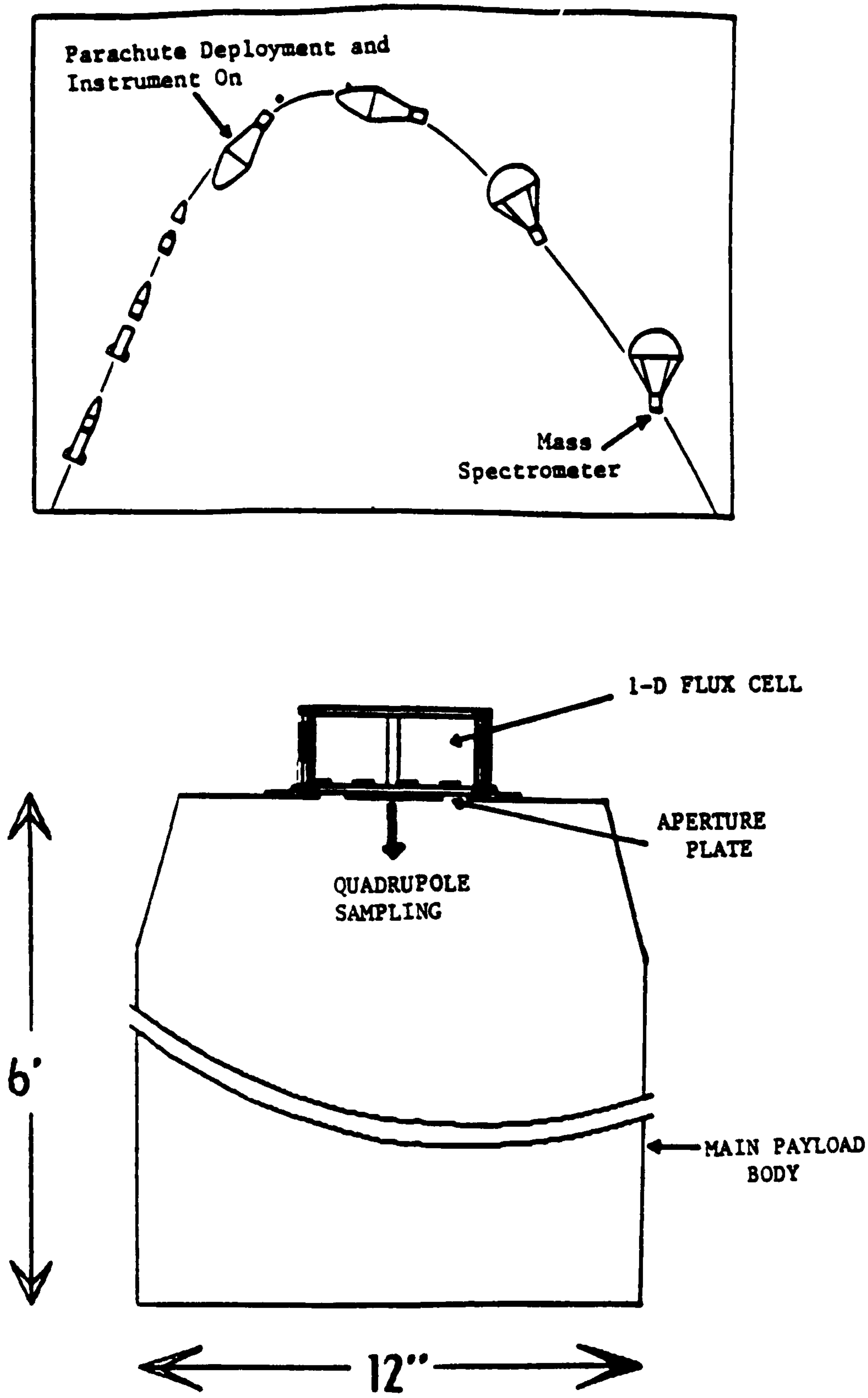
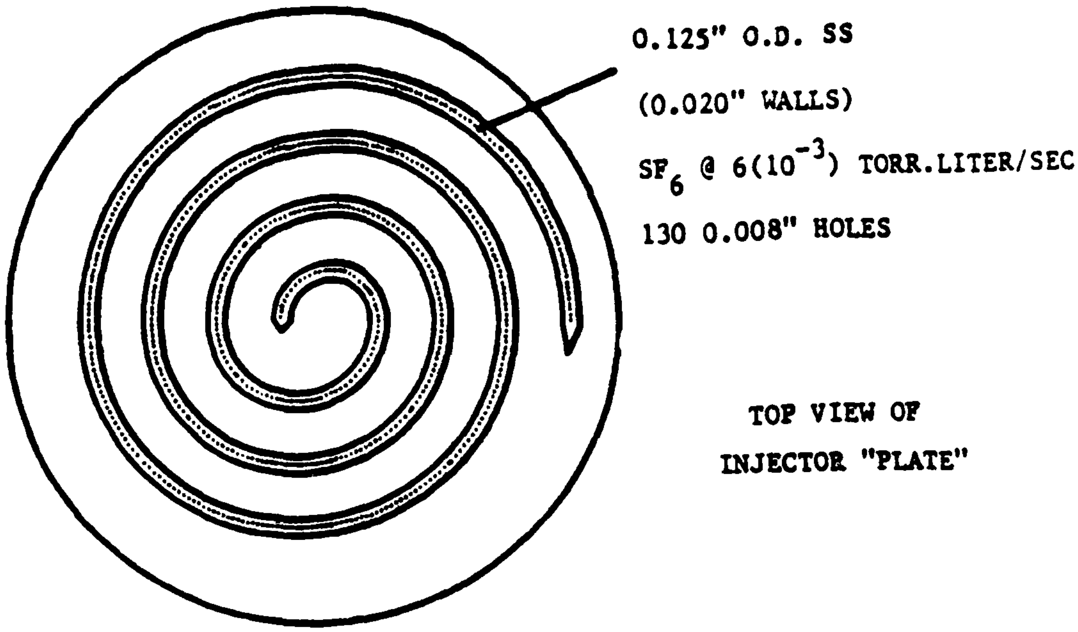


Figure 1.1. Illustration of launch, deployment and mass sampling scenario (Top Panel, adapted from Project DROPMAS). Lower panel illustrates the main payload body and configuration of 1-D Ion Flux Cell relative to the aperture plate and region of quadruple ion sampling.

1-D ION FLUX CONTROL CELL



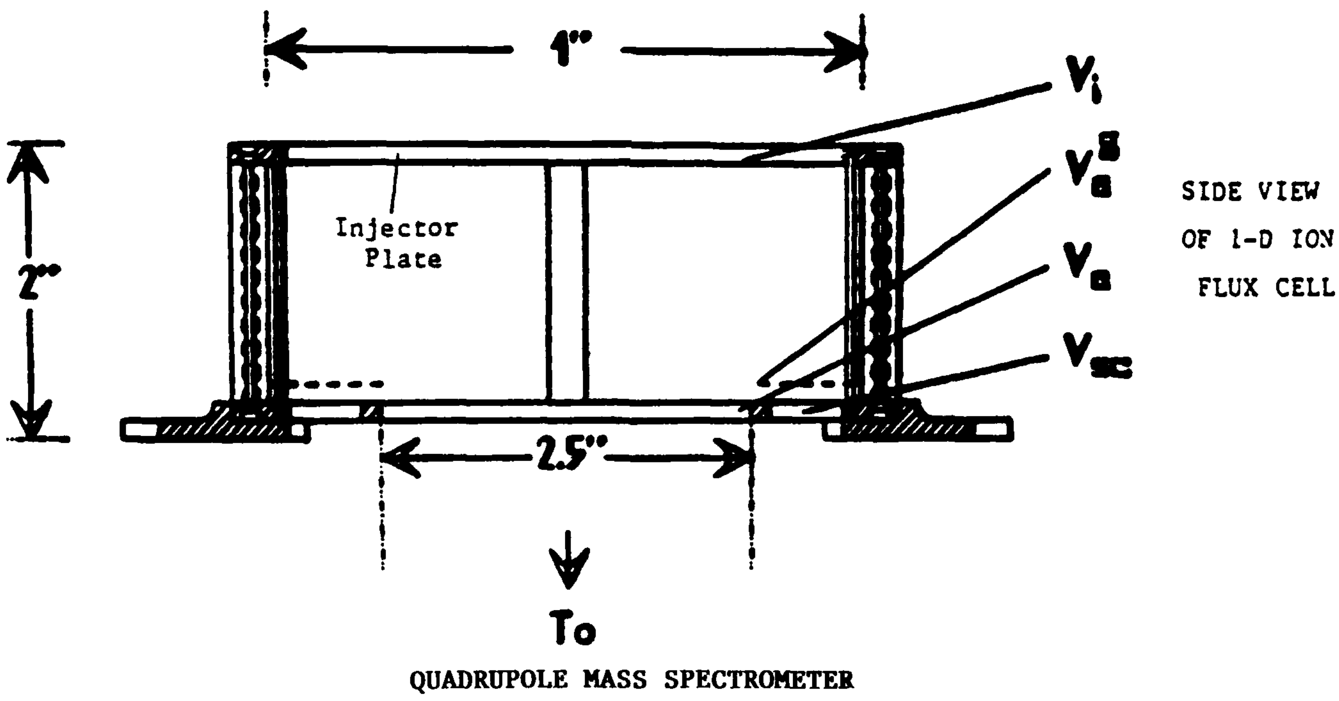


Figure 1.2. Bottom panel illustrates side view of the 1-D Ion Flux Cell. Applied potentials include V_i (injector voltage), V_a (aperture voltage) and V_a^g (guard voltage = V_a). V_{sc} represents the payload potential. Top panel illustrates the injector plate constructed from an open helix with 0.008" holes for forward injection of SF_6.

sampled negative ion distribution. The overall SAIC task involved: (1) the design of the front-end sampling technique, (2) the development of a first-principles model which predicts the relationship between measured values of SF_6^- and the ambient free electron population, (3) the development of concepts and designs for direct N_e measurement techniques, and (4) the adaption of the SAIC plasma facility for flight simulations.

3. Approach to the Problem

Recommended front-end design. The 1-D ion flux cell design focused on a pillbox geometry with a 2" height and a maximum diameter allowable in the launch vehicle configuration (see e.g. Figures 1.1 and 1.2). Other design drivers included a guard electrode for the aperture plate and controllable potentials to the injector plate V_i, the aperture plate V_a, and the guard electrode V_g^a. In all cases V_a and V_g^a were to be equal. Design guidelines also included the measurement capability of bipolar currents at the injector surface and the aperture plate. To minimize dielectric charging on active surfaces, all electrode surfaces were to be gold plated.

Ion sampling and SF_6 injection. Relative to SF_6 injection and ion sampling, the following recommendations were made: (1) that ion sampling begin on the upleg portion of the trajectory before SF_6 injection was initiated. The preferred mode would involve the delay of SF_6 injection until apogee. (2) that the ion sampling format be based on a "minimum mass spectrum requirement" (see Table 1.1.), (3) that voltage differences between the injector and aperture plate not exceed an absolute value of 2 volts, and (4) that the injector plate be operated at the local plasma potential. We note that a tight payload preparation schedule precluded the implementation of the last recommendation.

Sampling Phenomenology and Modelling Perspectives. Figure 1.3 illustrates the phenomenological domains that affect the overall sampling process and accordingly drives the attendant modelling activity. Region 1 defines the domain outside the 1-D cell and forward of the payload. In this region two major elements control the charged particle flow from the ambient environment to the injector surface: (1) a penetrating electric field if the injector plate is not held at the ambient plasma potential, and (2) the ambient flowfield as defined by the ambient particle distributions and the relative velocity in the payload frame.

The optimum sampling configuration involves no field penetration into Region 1. Such a field would penetrate to relatively large distances (because of low charge densities, effects of high charge-neutral collisionality, and resulting degradation of plasma shielding); it would risk modification of the ambient charged particle mass distributions (e.g. through fractionation), and necessitate a three-dimensional code with end effects and fringing fields.

Since the payload preparation and launch schedule did not allow time to prepare the electronics to track the local plasma potential and apply appropriate voltage levels to the injector plate, an approach was adopted to apply several levels of voltage to the injector, and plan for post-flight analysis to determine the values and conditions under which the

Table 1.1. Minimum mass spectrum requirements.

POSITIVE IONS		NEGATIVE IONS	
Mass	Specie	Mass	Specie
19	H_3O^+, F^+	19	F^-
30	NO^+	32	O_2^-
32	O_2^+	35	Cl^-
37	$H_3O^+ \cdot (H_2O)$	60	CO_3^-
38	F_2^+	61	HCO_3^-
55	$H_3O^+ \cdot (H_2O)_2$	62	NO_3^-
		78	$CO_3^-(H_2O)$
73	$H_3O^+ \cdot (H_2U)_3$	80	$NO_3^- \cdot (H_2O)$
		93	$NO_2^-(HNO_2)$
109	$H_3O^+ \cdot (H_2O)_5$	97	HSO_4^-
145	$H_3O^+ \cdot (H_2O)_7$	125	$NO_3^-(HNO_3)$
		127	SF_5^-
		146	SF_6^-

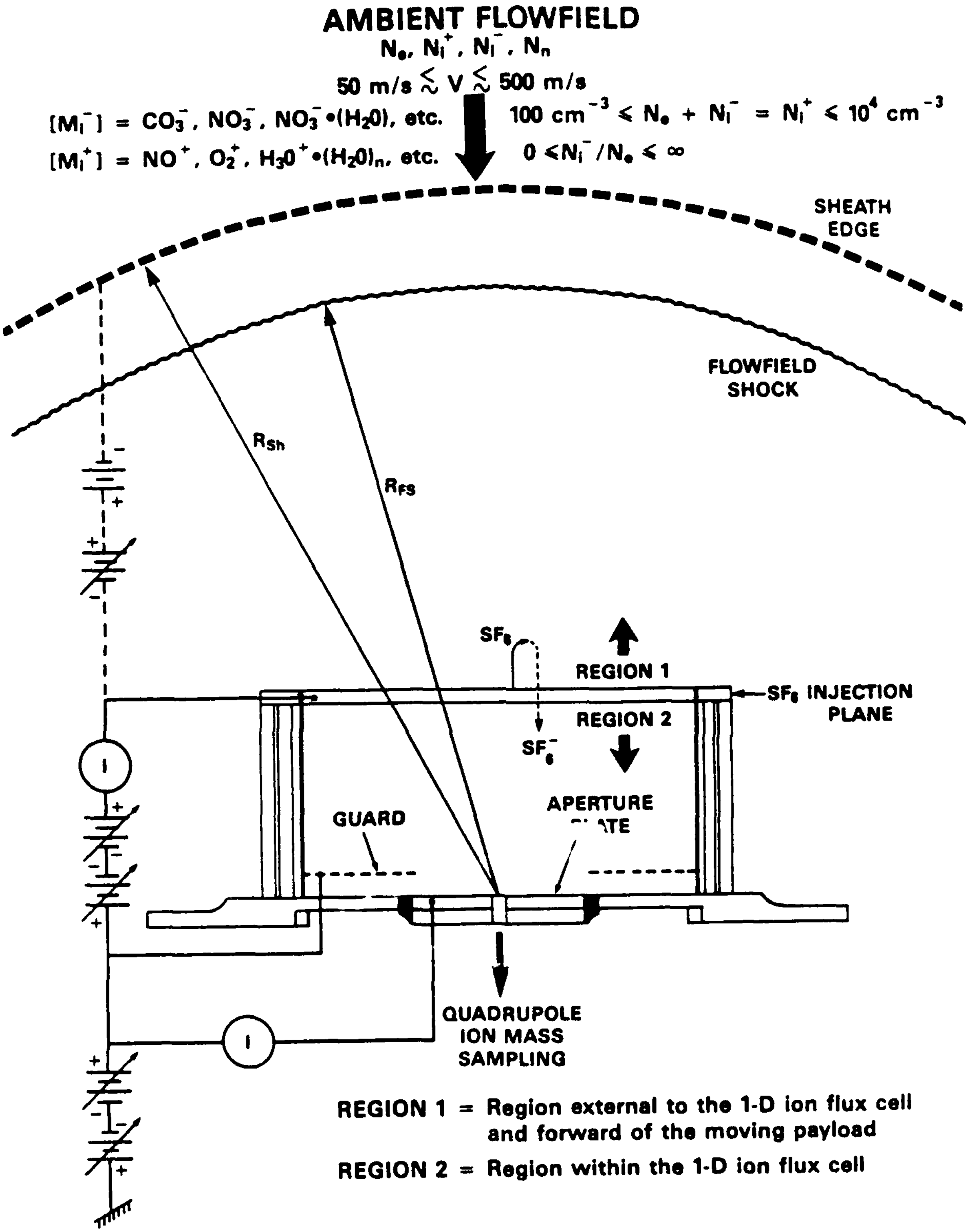


Figure 1.3. Phenomenological domains in the sampling process.

injector was at or closest to the local plasma potential. AFGL/LID selected -5, -1, -.5, 0, +.5, and +1 volts for the positive ion collection mode and -1, -.5, 0, +.5, +1 and +5 volts for the negative ion collection mode. For purposes of pre-flight modelling, zero electric field penetration into Region 1 was assumed.

With zero field penetration assumed in Region 1, analysis focused on the flowfield effects on the transport of charge from the ambient environment to the injector surface. While the numerical flowfield simulation included Region 1 (i.e. the domain within the 1-Dcell), initial emphasis in the simulation focused on the flowfield input to the 1-D cell, and the use of those results as an input boundary condition for a Particle-in-Cell (PIC) code which calculated the transport of all charged species from the injector plate to the mass spectrometer aperture. The PIC code was designed to include flowfield collisionality and electric field effects.

4. Report on Results

SAIC's detailed report (October 1988) treated the issues in a fashion that allowed the reader to develop a progressively increased perspective on the elements that needed to be brought to bear in solving the sampling problem and in the interpretation of the "in situ" measurements. In Chapter 2, SAIC provided an overview on the ion chemistry and attendant ion distribution in the ambient and SF_6-perturbed environments at altitudes of interest to the program objectives. This helped establish an appreciation for the complexity of the charge distributions, the sensitivity to fractionation, the requirements on ion mass sampling, and the height distributions of free electrons. Chapter 3 applied a straightforward approach to establishing the importance of charged and neutral particle collision frequencies, allowing the test particles to be thermal or to have an accelerated energy. The approach involved both collision frequencies and collision mean-free-paths for appropriate comparisons with plasma parameters and system lengths. In Chapter 4 SAIC provided a first-order analytical approach to the controlling physics within and outside of the 1-D Ion Flux Cell. The analytical perspectives set the framework for the more detailed computational results of flowfield distributions (Chapter 5) and charged particle transport (Chapter 6). From some perspectives Chapter 6 represented the final objective of the modelling task ... the final calculation of charged particle fluxes arriving at the aperture plate of the ion mass spectrometer. Chapters 5 and 6 also reviewed a relevant subset of the accumulated "in situ" observations, and compared the findings with model predictions. The comparison of model predictions with experimental results was extraordinarily good, and should provide the foundation for publications in the reviewed scientific literature. In addition, Chapters 5 and 6 discussed code refinements and experiment assumptions that were exercised in order to more completely understand the instrument performance and more accurately extract the sought-after values for ambient charged particle densities. Chapter 7 then provided summary comments and conclusions.

L. FEASIBILITY OF RADIO-BLACKOUT MITIGATION IN THE BRAKING PHASE OF AOTV OPERATIONS (TRN 18)

Performing organization: SAIC
Dates: 4 December 1987 through 30 September 1988
Personnel: D. Rault, E. Szuszczewicz, and G. Earle

This year, SAIC has developed a new numerical tool to investigate the feasibility of mitigating radio blackout around a reentering vehicle like the Aeroassisted Orbital Transfer Vehicle (AOTV), and its forerunner, the Aerobraking Flight Experiment (AFE), by injecting electrophylic gases into the vehicle wake. In most of the braking phase of the AFE, the ambient gas density in the near wake of the vehicle is so low that standard fluid codes are not applicable. Therefore SAIC used the Rarefied Aerodynamic Characteristics Evaluator (RACE) code, designed specifically to simulate flows in the transition and free molecular regions for multispecies gases, with and without chemical reactions, and internal energy transfer. RACE is based on the Direct Simulation Monte Carlo Method developed by Bird.

The first objective in the SAIC application of RACE to the blackout problem was to demonstrate that the code could reliably predict the fundamental features of supersonic wake flows. In the continuum region, wake flows are characterized by a large recirculation region, a wake shock, a free shear layer and a lip shock (Fig. 2.1). RACE reproduced these basic features; Figs. 2.2 - 2.4 show the flowfield, density distribution and density gradient distribution (akin to Schlieren picture) for a 2D flow past a rectangular step of a monatomic gas at free stream Mach number of 4.

The second objective was to determine the effect of an electrophylic injection (e.g. SF_6) on the flowfield in the near wake and obtain a first qualitative estimate of the "diffusion" of the electrophylic into the air flowfield. Figs 2.5 - 2.6 show the SF_6/air density ratio in the wake of a 2D rectangular step for two different SF_6 injection rates. It can be seen that the injected SF_6 completely destroys the vortical motion of the air, but only barely penetrates into the high velocity air stream. Quantitative results, such as the actual mass flow rate of SF_6 injection to achieve a 1% SF_6/air ratio outside the wake, could not be determined since the simulation was done in 2D Cartesian. Further simulation will be done in 2D Axisymmetric.

SAIC now has in place the proper numerical tool to characterize and quantify the electrophylic injection requirements for mitigation of blackout effect. In the next phase of the work, we plan the following steps:

1. Check the dependence of present results on computational grid structure,

2. Study possible interface problems between computational domain regions, which could lead to a reduction of SF_6 transport to outside flow,

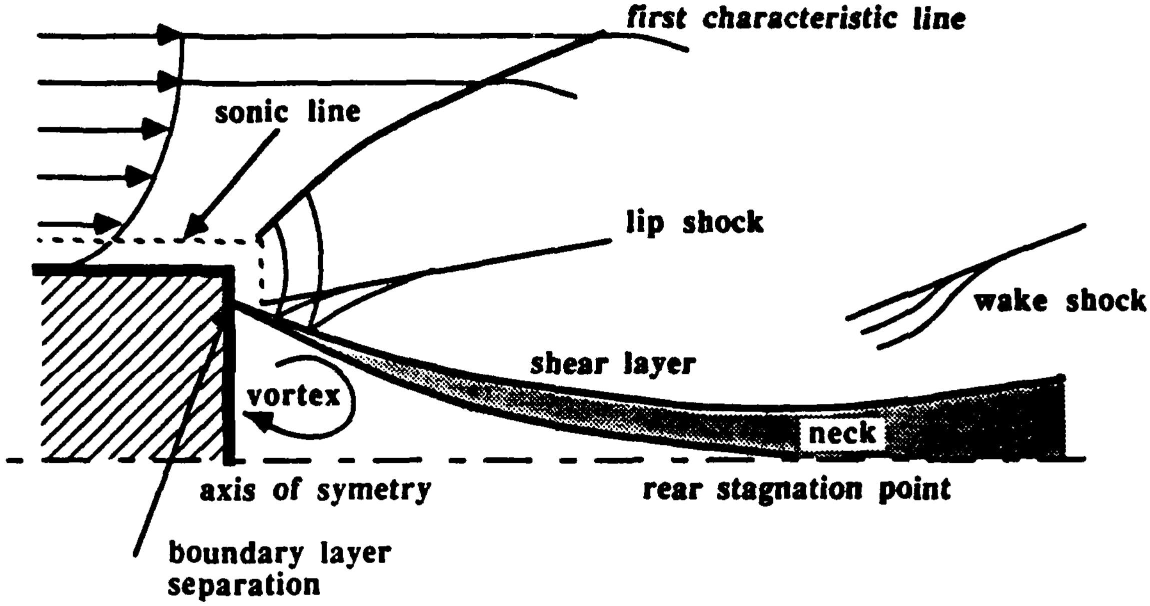


Figure 2.1. Supersonic flowfield structure in the wake of blunt bodies. Effect of viscous forces.

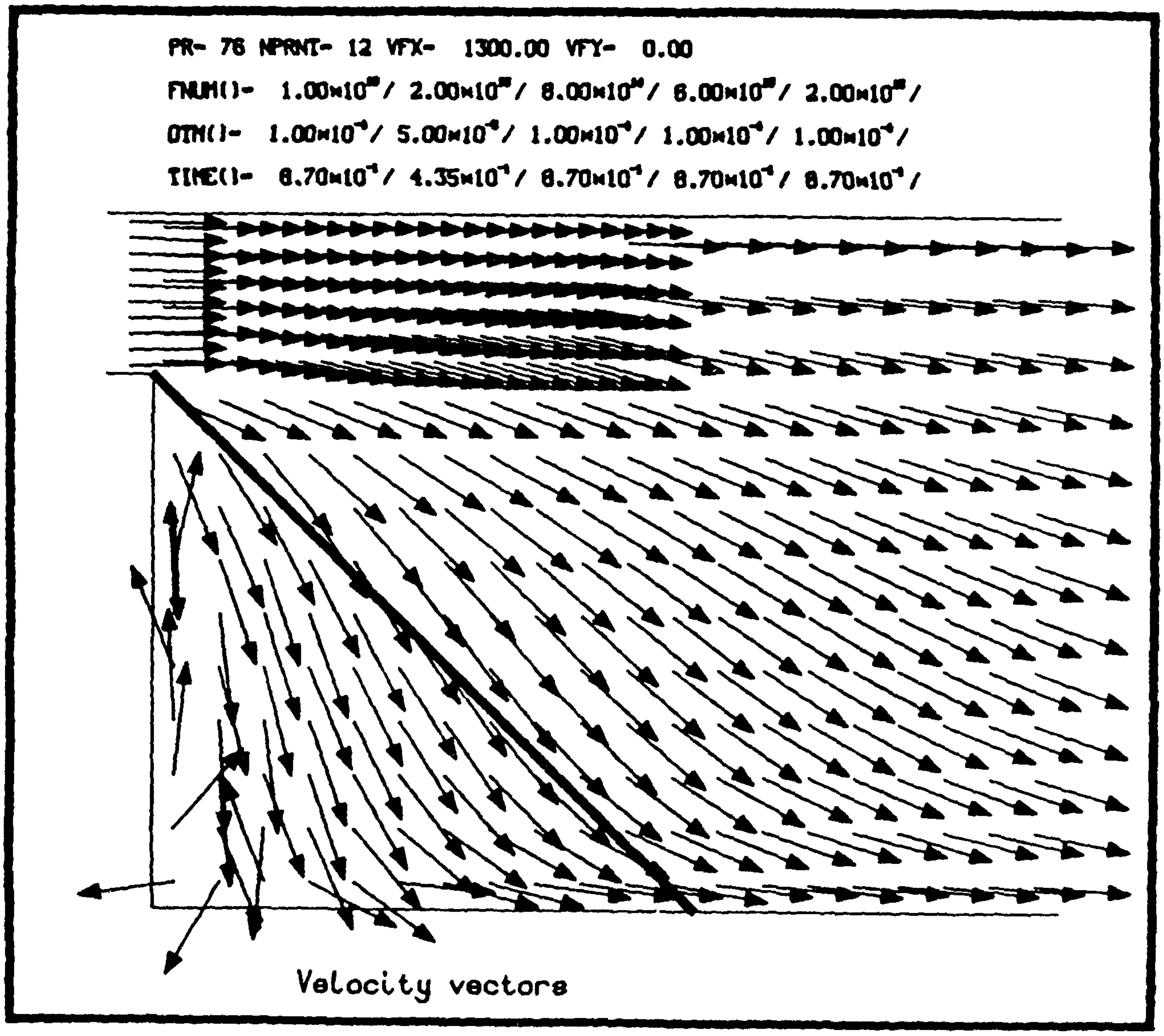


Figure 2.2. Air flowfield in the wake of 2D step (Mach = 4).

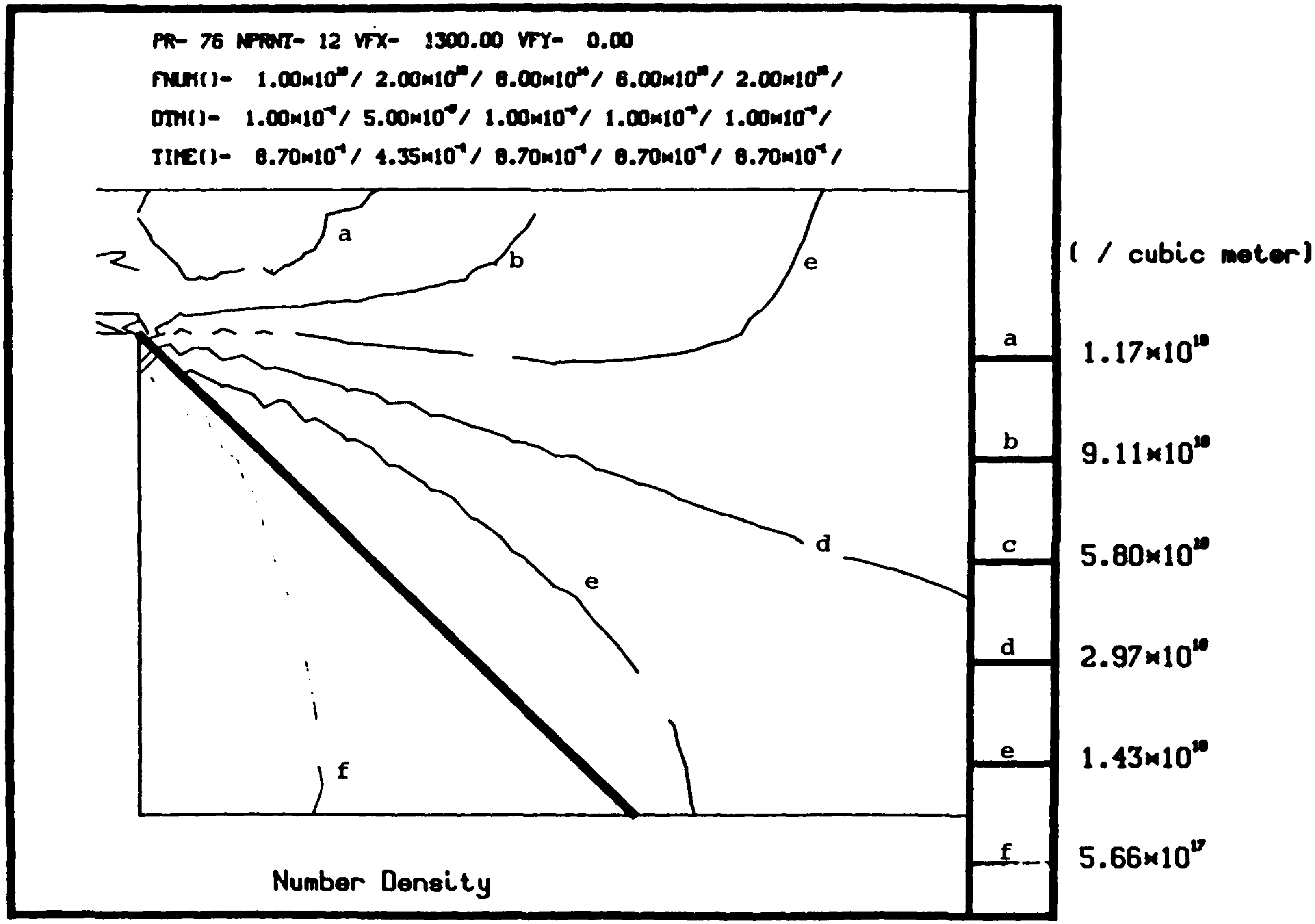


Figure 2.3. Number density contours in the wake of 2D step (*Mack* = 4).

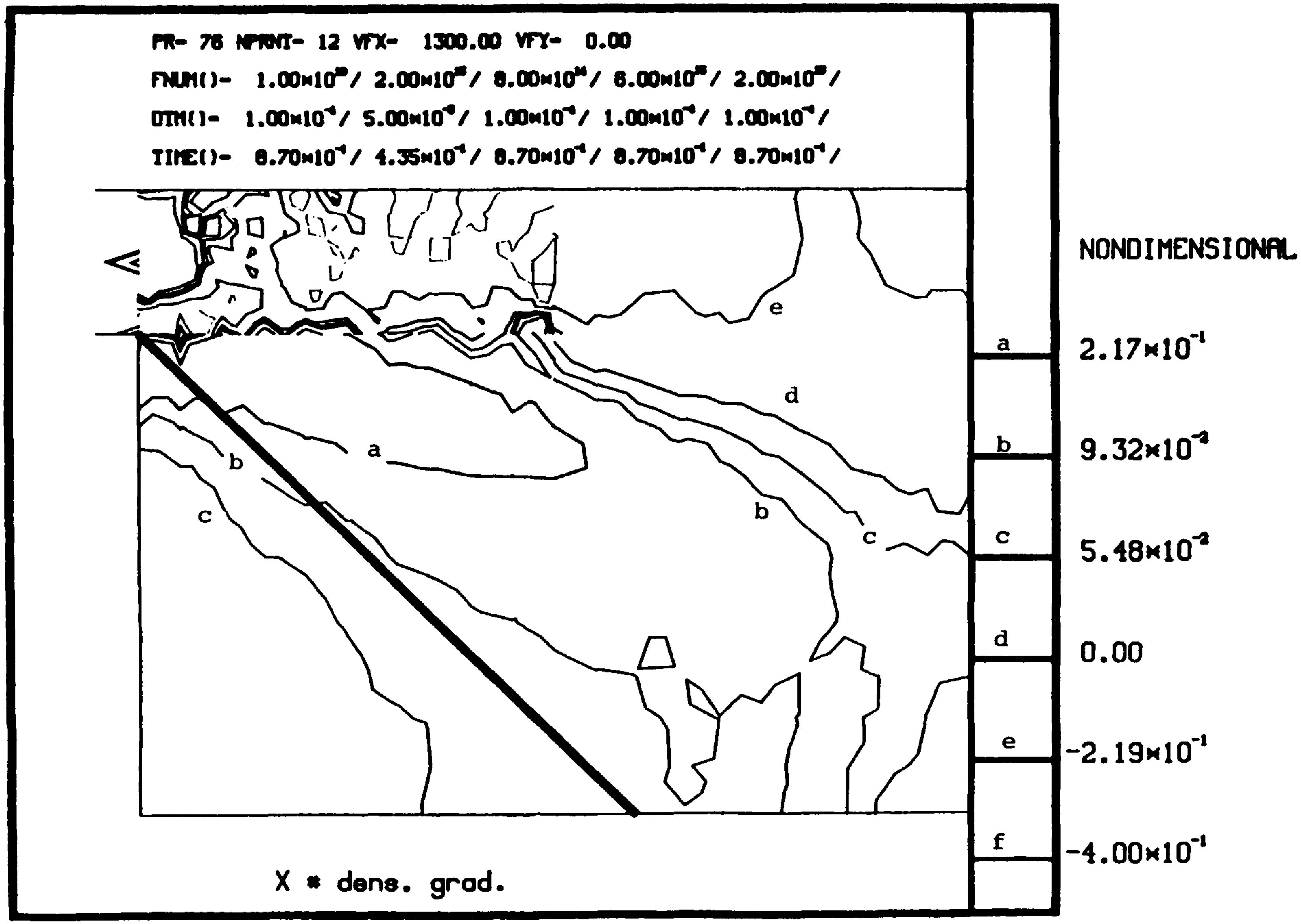


Figure 2.4. Density gradient in the wake of 2D step (Schlieren picture).

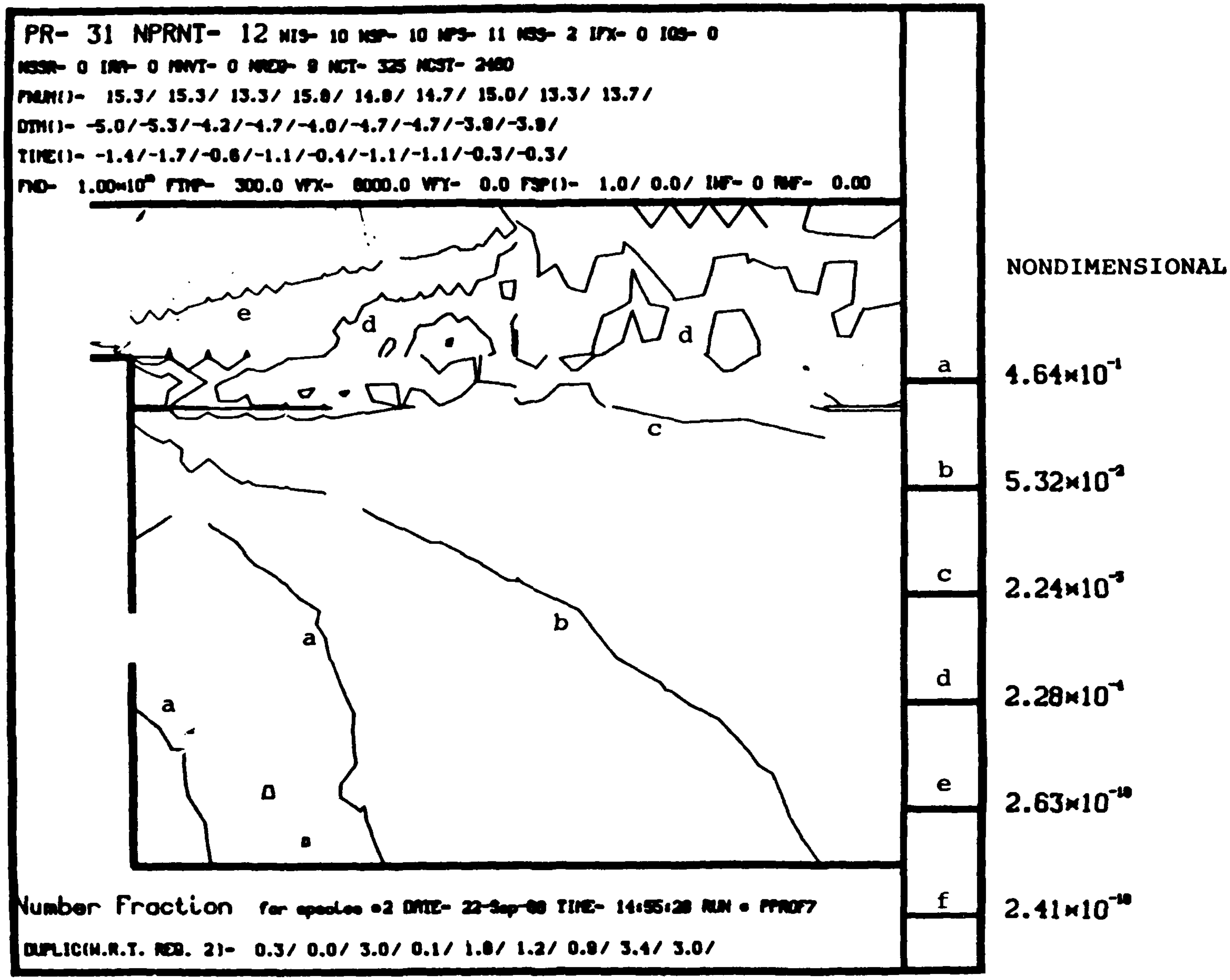


Figure 2.5. Number density fraction SF_6/air (low SF_6 injection rate).

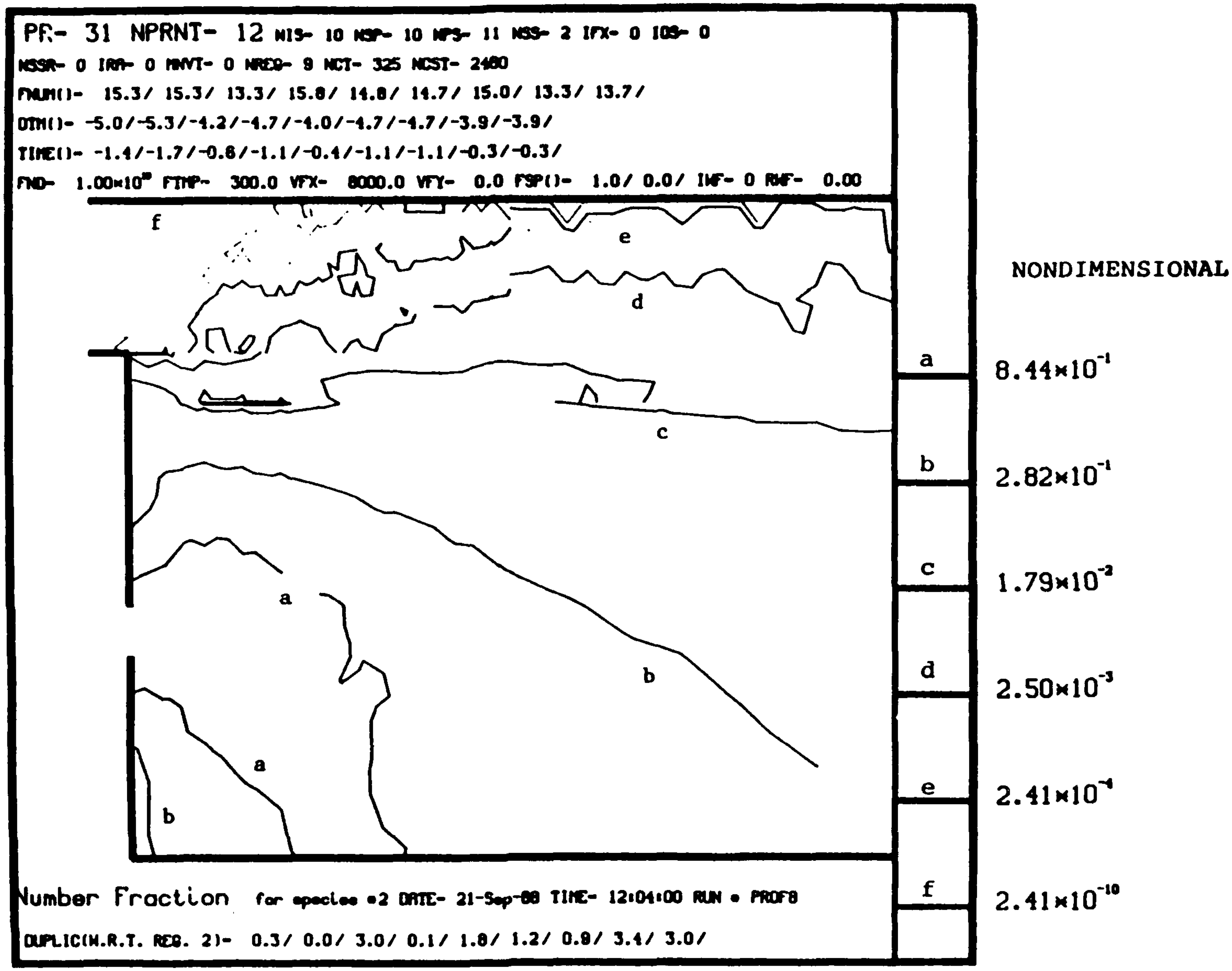


Figure 2.6. Number density fraction SF_6/air (high SF_6 injection rate).

3. Run simulation in 2D axisymmetric to include 3D effects and obtain a measure of the SF_6 injection flow rate,

4. Use ram results from NASA as input boundary conditions to wake flow. When using continuum simulation results, determine the "breakdown surface,"

5. Include chemistry between SF_6 and electrons,

6. Optimize code for vector machines to reduce CPU time.

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